The Hollow Sperulites of the Yellowstone and Great Britain.
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14. THE HOLLOW SPHERULITES *of the* YELLOWSTONE *and* GREAT BRITAIN. By JOHN PARKINSON, Esq., F.G.S. (Read March 6th, 1901.)

[PLATE VIII.]

CONTENTS.

I. INTRODUCTION.

IN a paper which I had the honour of presenting to the Geological Society some time ago on the Pyromerides of Boulay Bay,[1] I explained the formation of these nodules by supposing the extrusive magma in which they were produced to be imperfectly mixed and in a somewhat viscous state, a conclusion which facts in the field appear amply to justify. These, and other nodules which I studied in North Wales and near Wrockwardine, led me to suppose that the dominant characteristic of these peculiar structures was not that of spherulitic growth, which rather was secondary, and that the principal cause operating in their formation, as just remarked, was a clotting in the magma by a process of flow-brecciation. At the same time, I did not suggest that this was the sole means by which pyromerides were produced, and moreover I purposely left some of the structures which are found, notably the not infrequent concentric arcs of quartz, for later consideration and discussion. Recently, in crossing the American continent, I made a detour to the Yellowstone Park with the object of studying the obsidian there, and it is the result of this excursion which has led to the putting together of the following notes. Since the paper above referred to was written, I have examined the rocks of Boulay Bay and Wrockwardine for the third and second times respectively, and have studied those of Pontesford Hill.

The general features of the National Park of the United States are too well known to need more than brief mention; I would, however, refer to the recent monograph by Prof. Iddings in the Memoirs

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 101.

of the United States Geological Survey, vol. xxxii, pt. ii, and to the Geologic Atlas of the United States, folio 30. The latter contains the Survey maps and a general description of the topographical and geological features, together with a brief summary of the igneous rocks by Prof. Iddings.

I have studied these acid lavas at two points: firstly, at the well-known Obsidian Cliff, and, secondly, at the Cañon of the Yellowstone River. The rocks at these two localities differ one from the other in a most unusual manner. At Obsidian Cliff is seen a magnificent section of an obsidian lava-flow, the lower two-thirds columnar, the upper part crowded with large hollow spherulites; at the Cañon the effect of solfataric action on the rhyolite has converted the great thickness of these flows, which now form the walls of the Cañon, into the friable many-coloured rocks which constitute one of the greatest attractions of the Park.

[Part I—The Yellowstone.]

II. Description of the Rocks of Obsidian Cliff.

The glass.—At Obsidian Cliff this is black, but in other places, as, for instance, locally at the Cañon, a streaking together of red-brown and black glass is not uncommon. Where spherulites abound, the glass of course decreases in quantity, merely filling interstices, and is occasionally almost entirely absent. In a thin section the glass appears clear and transparent, and crowded with trichites and microlites.[1] It is too well known from the work of Prof. Iddings to require any description.

The smaller spherulites admit of division into two groups:—

(i) This contains bluish-grey spherulites which are usually solid, hard, and compact in texture, with a well-marked radial structure. Not infrequently, the interior of the spherulite becomes hollow, and the cavities of adjacent individuals communicate. These hollows have a tendency to be stellate in outline, and not rarely the greatest length is normal to the direction of the flow-band. Their walls are usually formed of a narrow layer of brown earthy material, external to which we find the harder bluish-grey spherulite.

(ii) In this subdivision radial structure is almost entirely absent, and cavities are invariably found. A thin border of whitish, rather crumbly material around the cavity represents the spherulite, and strings of such forms are embedded in the black glass. Occasionally we find an approach to the harder blue spherulite of the foregoing group, the more coherent material being external to the white crumbly layer. Lines and bands of these spherulites are common in the lower parts of the obsidian-columns, and often measure only ·025 inch across. The cavities are large in proportion to the diameter of the spherulite, and are almost always arranged with their longer axes normal to the direction of flow. When the

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 273 & pl. xv.

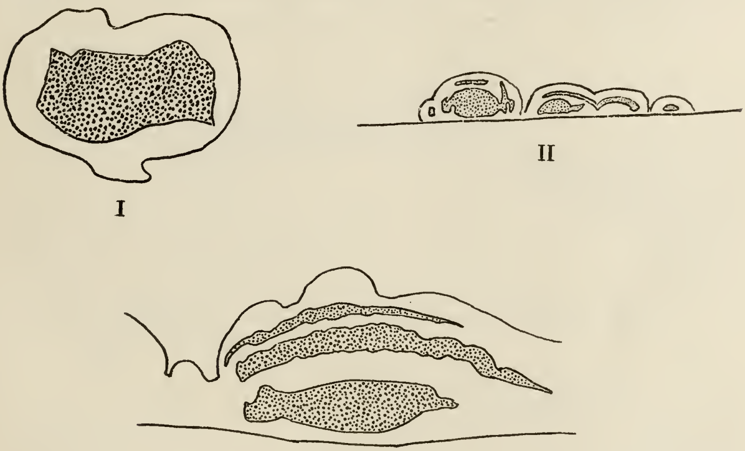
cavities of adjacent individuals communicate, these hollows naturally become irregular; and often the whitish material is aggregated in porous or cavernous bands or clots, measuring up to ·5 inch across.

Hollow spherulites proper.—If any large slab of rock forming part of the talus at Obsidian Cliff is examined, it is seen that the cavities of the spherulites possess many shapes. Often they exhibit a concentric disposition around a large central hollow; sometimes the concentric arrangement of smaller cavities is almost absent; in a third case the vesicles are irregular and even stellate; while in a fourth they are almond-shaped and elongated in the direction of flow.

These cavities will be considered under two heads:—

(i) Those without definite form.[1]—One example, irregularly stellate, was surrounded by a mere shell of spherulitic growth in which a radial structure was just discernible (fig. 1, I). The

Fig. 1.—*Cavities in the spherulites of Obsidian Cliff: natural size.*

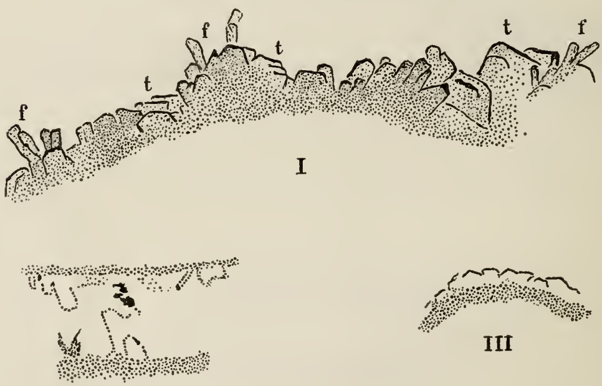


spherulite itself was pale pinkish-white in colour, and the interior of the cavity and part of the wall, as seen on a fractured surface, were granular. Crystals of fayalite were embedded in and on the walls. The exterior of the spherulite was slightly irregular, a small blunt tongue projecting out in one place into the surrounding material. This consisted partly of glass, partly of lithoidal flow-bands. The stellate form of the cavity may be best conveyed by imagining that a blunt wedge was thrust outwards from the cavity into the yielding substance of the spherulite. In one place the walls met at a right angle.

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 264, pl. xii, figs. 1 & 5.

(ii) Cavities with a definite form.—Almond-shaped cavities, frequently elongated till they resemble a rift in the rock rather than an ordinary vesicle, are common. Such a rock resembles a series of plates, 1 inch thick and upwards, imperfectly welded together, and containing many interspaces. Usually these plates are lithoidal, but contain patches and streaks of the black glass. For instance, we find an elongated porous spherulite an inch or so in length, contained between two hard compact flow-bands and embedded in glass at either end. It consists of an aggregate of crystals which in places are only loosely set together, and at one end contains three small hollows, the greater length of which is at right angles to the direction of flow. Such a spherulite, when the cavities are more fully developed, presents an arrangement of concentric rings lying in a plane parallel to the flow-bands. This is the typical lithophysal structure.[1] The concentric rings, which in a cross-section bridge a cavity, consist of a rather coarse granular aggregate of crystals of felspar and tridymite (fig. 2). From the

Fig. 2.—*Hollow spherulites.*



I = Outer edge of one of the series of concentric rings which distinguish the lithophysæ of Obsidian Cliff, showing the projecting crystals of tridymite (*t*) and felspar (*f*). ×40.
II = Interspace between two rings of a lithophysa from near Wrockwardine, showing remnants of projecting crystals (see Pl. VIII, fig. 2). ×45.
III = Remnants of a mineral resembling tridymite, from near Wrockwardine. See p. 221. ×45.

almond-shaped rifts we obtain gradations to other kinds of hollow spherulites. Thus, by decreasing the length of the cavity parallel to the plane of flow, and broadening it in a direction at right angles to that plane, we arrive at an ordinary hollow hemispherical spherulite lying on a flow-band. Such a cavity shows relation to

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 264 & pls. xii & xiii; for chemical analyses of the obsidian and lithophysæ, see *ibid.* p. 291.

its spherulite by a parallelism at the ends of the latter, or by its general concentric form. On the flat surface of a specimen we often see an arc-like disposition of cavities subtending angles up to 180°; two such arcs are often concentric one to the other.

One fine pink spherulite measuring about $1\frac{1}{2}$ inches by 1 inch, clearly traversed by the flow-lines which run through the rock, possesses an open and porous texture, preserving at the same time its spherulitic habit. On the upper side of a flow-band, and, as it were, springing from it, the spherulitic growth is distinctly visible to the naked eye, and by the aid of a low-power lens is resolved into bundles of branching rays, the free ends of which project into a crescent-shaped cavity. Much tridymite adheres to these fibres, but above the rift the spherulite is more solid in texture and the radial structure less readily recognizable. Through this part fine flow-lines can be traced. Below the band coarse tufts again appear, also connected with a cavity, and extend for the entire length of the spherulite. These fibres pass into the more compact portion of the spherulite, and apparently differ in no respect from it except in habit.

In this instance the cavities of the spherulite are related (*a*) to a flow-band, and (*b*) to the periphery of the spherulite.

The lithophysæ of Obsidian Cliff graduate into another common variety, distinguished by a porous structure and by the absence of a definite cavity. An entire absence of a cavity is, perhaps, rare, but it is not structurally important. Such forms may be conceived of as lithophysæ in which the cavities have been distributed through the body of the spherulite and not localized or arranged in a definite way. These porous spherulites are irregular, lobate, or circular in outline: often the outer zone is harder and less friable than the central portions, and shows traces of a radial growth.

III. Statement of the Problem.

The preceding description demonstrates that no distinction can be drawn between the various kinds of spherulites described. Even the bands of hard bluish-grey spherulites are found frequently to possess small central cavities, and by gradation to merge into those in which the cavity is the dominant feature. Between such and the typical lithophysæ no distinction can be made that would indicate a difference in mode of formation, since all stages can be observed connecting the two.

It remains, then, to see what explanation best accords with the varying forms of structure which the rock presents, and if possible to bring to light the fundamental property of the original magma to which they owe their birth; or, on the other hand, to see whether decomposition by heated waters may not be responsible for the whole or for part of the observed facts. To this end, let us investigate first the effect of solfataric action as revealed in the rocks of the Yellowstone Cañon.

IV. The Effect of Solfataric Action in the Cañon of the Yellowstone.

In a road-cutting within a few yards of the Upper Falls of the Yellowstone is a dark chocolate-coloured rhyolite, streaked with a brighter red, and containing many porphyritic crystals of felspar and quartz. The rock possesses a fluxional structure and numerous fragments attributable to flow-brecciation. In a thin section it appears brown and opaque, with a very obscure spherulitic structure, together with a rather blotched appearance as though the constituents had gathered themselves into a series of nodes and irregular patches. These are separated by light-coloured streaks consisting of tridymite and opacite. In a few yards the character of the rock changes considerably. Small spherulites weather out from the dark grey surface, but fracture discloses a reddish-purple rock studded with porphyritic felspars, and especially noteworthy for the milky-white cavernous patches spread through it. In a thin section we see that no dividing line can be drawn between altered and unaltered parts, so insidiously has the intruding silica permeated, and so gradually does the change take place. The staining of the rock, probably by iron, and the obvious silicification which it has undergone, are no doubt due to the permeation of hot water charged with silica, and apparently during this process parts of the rock have been entirely removed.

A specimen of uniform milky-white rock, containing light grey fragments in such quantity as to recall an ash, was collected from the crags overlooking the Great Falls of the Yellowstone. Within a couple of yards we find pale grey spherulites about an inch in diameter, which for the most part, at least, are not hollow. Probably, then, the rock is a rhyolite, and the fragments are due to flow-brecciation. A thin section shows that the structure of the rock has been preserved, save for a slight indistinctness in the outline of the fragments. More transparent patches, such as distinguished former specimens, are not found, and streaks of opaline silica are not uncommon. Between crossed nicols there is no action on polarized light.

A few slides of spherulites from a friable obsidian near the Upper Falls of the Yellowstone have been prepared, and are of some interest. Firstly, they are almost identical in form and structure with their far older representatives of Boulay Bay, except for the greater number of porphyritic crystals that they contain; and secondly, they bear no evidence of silicification or alteration.[1] In a thin section the type of radial growth strongly recalls that of Boulay Bay and of the small blue spherulites of Obsidian Cliff. The slice

[1] This statement admits of some modification. Occasionally one finds an oblong or irregular patch, more translucent than its surroundings, and distinguished by the absence, more or less complete, of the felspathic fibres, and by the presence of a colourless almost isotropic substance which may be tridymite.

is brown and rather opaque, exhibits the mottled appearance of the Northern Jersey rocks, and traces of flow-structure exist. Porphyritic crystals of quartz, unaltered orthoclase, and plagioclase are common, the last predominating. In one slide an elongated cavity is cut through, into which a porphyritic, absolutely unaltered orthoclase projects. This cavity is lined by rather impure carbonates, while some discoloration of iron-oxide exists in the neighbourhood, but no sign of replacement or of solution. This indicates that the spherulite is more resistant to the action of hot water charged with silica than are its surroundings.

The cavernous hollows with a rough mammillated lining, found in the altered rhyolites of the Upper Falls, and referred to above, closely resemble at first sight some spherulites with irregular vesicles from the obsidian of Obsidian Cliff. The concretionary material which lines the cavities in the rock of the last-named locality is easily powdered, and consists of branching rays of dusky felspar and tridymite. In the altered rhyolite the similar material is much harder, and no felspathic fibres appear. The encrusting substance is probably largely tridymite, which mineral it resembles in its index of refraction and polarization-tints; but the characteristic hexagonal outlines are not seen, perhaps owing to the fact that the constituent scales are more closely aggregated.

We may conclude that, the action of hot water charged with silica may be to remove portions of the rock, or to permeate it without destroying its characteristic structure; we obtain, however, no evidence, but rather the reverse, to show that the spherulites are most easily attacked.

V. Conclusions in regard to the Yellowstone.

The theory formulated by Prof. Iddings [1] to account for the structures exhibited by lithophysæ at Obsidian Cliff and elsewhere in the National Park is, in my opinion, that which is most in accord with the facts. It is based on the hypothesis that the origin of lithophysæ is due to the hydrous state of certain parts of the magma. In an additional memoir, recently published,[2] three physical processes have been given as the means by which the formation of lithophysæ was carried out. These are, in the first place, rapid crystallization; in the second, 'a sudden liberation of heat' resulting therefrom; and in the third place, a consequent 'lowering of saturation of the surrounding mother-liquor.' Thus he arrives at the 'spasmodic advance of crystallization' resulting in 'layers' of varying coherence, and the ultimate formation of open spaces by 'shrinkage.' In order to test the truth of these hypotheses by independent data, I have consulted Berthelot's 'Mécanique Chimique' and kindred works, and have also

1 7th Ann. Rep. U.S. Geol. Surv. (1885-86) p. 284; for an historical review of the theories relating to lithophysæ, see *ibid.* p. 287.

2 Mem. U.S. Geol. Surv. Monogr. xxxii, pt. ii (1899) p. 417; see also Bull. Phil. Soc. Washington, vol. xi (1891-92) pp. 446-47.

endeavoured to obtain information concerning the latent heat of liquefied felspar, but without success.[1]

In a cooling magma we may conclude that the temperature gradually falls to the saturation-point when crystallization commences, and the rise in temperature produced, if any, would do little more than counteract the loss of heat due to the cooling of the magma as a whole.

If the part under consideration became supersaturated, some rise of temperature, no doubt, would ensue, though to what extent is doubtful. Supposing, however, heat to be produced by crystallization in a supersaturated solution, one deduction must be made for leakage into the surrounding rock, a second to counterbalance the fall of temperature in the whole mass, and it is only the balance which can be devoted to 'lowering the saturation of the surrounding mother-liquor.'

We find, then, some probability, at least, that the means which Prof. Iddings suggests are inadequate to the required end. In my opinion, that author's earlier work is more nearly in accord with the facts, and it is with this that the following remarks closely agree. No doubt can exist that when crystallization commences we have to deal with a hydrous patch in the magma, and that in this, as the temperature falls, anhydrous minerals develop. It is, therefore, clear that the remaining liquid—no doubt in a very viscous state—would become more hydrous, and the occluded vapour would be pushed away from the crystallizing zone, though part would be entangled in it and produce the characteristic porous structure. We have at this stage a comparatively solid portion succeeded by a vapour-laden belt, followed in turn by another area in which solidification is commencing.

The solid state of the part crystallized, and the viscous state of that in the act of crystallization, would prevent diffusion; and the process would be continued, until the whole of the hydrous patch presented the characteristic concentric structure.

[Part II—Great Britain.]

VI. Boulay Bay (Northern Jersey).

These peculiarities of structure in the spherulites and lithophysæ of the Yellowstone can often be paralleled in those at Boulay Bay and elsewhere in Great Britain, and thus afford great help in any investigation concerning the latter. Not infrequently in the old lavas we find concentric arcs composed of quartz, and roughly parallel with the periphery of the nodule. Occasionally the outermost is broad and well-defined, those nearer the centre progressively being less well marked (Pl. VIII, fig. 1). This tendency to fade away is shown (i) by the quartz-filled arcs becoming smaller; (ii) by the various portions of the arc becoming disjointed the one from the other, so as to produce a segmented appearance; and (iii) by the

[1] I wish to record my indebtedness, for invaluable help in this matter, to Prof. T. G. Bonney and Principal E. Carey Foster.

quartz-filled space itself becoming partly obliterated, owing to the presence of felspathic outgrowths principally from the convex side of the dividing walls. Passing towards the centre of the nodule we find, at last, the crescent-shaped areas represented by irregular grains of discoloured quartz, spread like cirrus-clouds through the brown nodule.

A perfect network of felspathic rods is seen also in many Boulay-Bay slides occupying the end of a crescent-shaped space, where this passes into the surrounding rock; while adjacent parts of the nodule appear to consist of felspathic fibres embedded in quartz. In the same way a haphazard section of a spherulite may show branching fibres of felspar projecting outward from a centre.

The felspathic outgrowths common enough in the nodular rocks of Boulay Bay are exceptionally well seen in the very similar rock from near Wrockwardine. In one instance the crescent-shaped rings are formed about a central amygdaloid. These rings, now consisting of infiltrated silica, are about ·035 inch across, and each is formed by two or more elliptical arcs joined together. From the convex side of these arcs spring rod-like growths of felspar, visible even to the naked eye, in a thin section. They stretch occasionally half-way across the quartz-filled space, and, in some instances at least, appear to have influenced the deposition of the infiltrated silica, for the mammillated layers can be seen to bend over the projecting fibres. (See fig. 2, II, p. 214, and fig. 3, p. 220.)

Not uncommonly at Boulay Bay we find evidence to show that porphyritic crystals of fairly large size, comparable with the fayalite of the Yellowstone lithophysæ, were present in this much older rock. They occur in a rather puzzling series of specimens from Boulay Bay and the Tête des Hougues, which possess a marked flow-structure, and appear to have been very vesicular.

A thin section of one rock shows that the greater part is spherulitic, and possesses a mottled appearance due to the separation of the particles during crystallization into a rather opaque greenish-yellow substance and a more translucent yellowish-brown one: both being fibrous. Many spherulites in the immediate neighbourhood exhibit precisely the same structure. In this rock lie innumerable amygdaloids, usually oval, and in some slides joined together so as to produce a rather vermicular appearance. The original vesicles, now filled wholly or partly with quartz, are sometimes lined by an irregular spherulitic growth stained with iron, containing specks of opacite, and slightly coarser than the opaque material surrounding it. Frequently we cannot define accurately the internal limit of this spherulitic ring, since the earliest layer of infiltrated quartz is usually discoloured. As in the hollow spherulites from Obsidian Cliff, the interior of the vesicle must have been exceedingly rough and uneven, and was probably provided with projecting spurs penetrating the cavity. A thin section, passing near the edge of such a spherulite after it had been filled up, would present a very confused arrangement between the infiltrated and the original materials. Occasionally a distinct lithophysal structure is found on a small scale.

In one or two instances a thin arc of quartz separates the inner spherulitic zone from the mottled fibrous material surrounding it; in others, curved or branching lines traverse the latter, and define a series of spaces, each possessing a distinct fibrous growth which differs in direction from that of adjoining areas. Such quartz-filled arcs and lines may be best accounted for by the supposition of contraction round a vesicle as described by Prof. Bonney.[1]

In another example the greenish material, but faintly mottled and with practically no radial structure, appears to have resolved itself into a number of globular forms roughly connected one with

Fig. 3.—*Parts of two rings of a lithophysa from the Wrockwardine district, showing the fibrous felspathic outgrowths.* ×30.

[Undotted spaces are filled with quartz.]

the other. A very confused crystallization, resembling that seen before, occupies the interspaces: these, for the most part, consist of discoloured quartz, separated indistinctly from the greenish matrix, which often seems produced outward into them in a hazy indefinite way. Embedded in the interspaces are the remnants of lath-shaped crystals, now entirely replaced by secondary products, and scarcely to be distinguished between crossed nicols from their surroundings. These, I think, are felspars; and I am led to this identification by comparison with other slides where an indubitable felspar has been altered in exactly this way.[2]

In other sections we find long lath-shaped crystals projecting into, or apparently lying altogether in, a cavity. They consist of a skeleton of iron-oxide, recalling the common alteration-product of

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 289.

[2] See 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 267, for the description of felspars in the lithophysæ and the cavities connected with them in the Yellowstone region.

mica. These crystals seem to be strictly analogous to those found projecting into cavities at Obsidian Cliff.

Evidence with the microscope and in the field shows that here is a series of rocks which were originally very vesicular lavas. A narrow margin of spherulitic growth formed around the vesicles, which appear either isolated or arranged by flow in a vermiform way through the rock. Points of resemblance can be found in those small blue spherulites of Obsidian Cliff which contain a central cavity. It was mentioned in Pt. I (p. 212) that these have a layer of brownish and somewhat friable material interposed between the central hollow and the compact hard outer zone; and probably it will not be erroneous to conclude that the distinct zone surrounding the vesicles of the Boulay-Bay rock is due to the presence of heated vapour from which the adjacent rock-material was unable to free itself during solidification.

VII. Wrockwardine (Shropshire).

The rhyolites of the district near Wrockwardine are well known. The greater part of the rock is of a dark chocolate-brown colour, as are also the nodules and smaller spherulites. Frequently surrounding the latter, and intermingled with the brown rock, is found a dark-green, rather soft substance, which is apparently of the nature of a residual glass. The nodules are usually lobate in outline, and stand out from a weathered surface much less commonly than is the case at Boulay Bay and in North Wales, and more frequently exhibit lithophysal structure.

Fig. 4.—*Cavities of lithophysæ from near Wrockwardine, now filled by infiltrated silica: slightly larger than natural size.*

This consists of a system of rings analogous to those from the Yellowstone region, which closely follows the periphery of the enclosing nodule, and may or may not surround a central quartzose amygdaloid (Pl. VIII, fig. 2 and text-fig. 4). The very complicated form which the entire system frequently assumes is due, I believe, to pressure after solidification: this pressure has broken down the concentric rings of rock, and usually connected the cavities to the central hollow when such exists.

The practical identity in the structure of the lithophysæ from the Yellowstone and Wrockwardine is still further emphasized by the presence, in the latter, of the remnants of a mineral which closely resembles tridymite in external form. It is rather sporadic in its occurrence, but locally encrusts thickly the walls of the concentric cavities of the spherulite. It is now replaced by quartz, so that the original polarization cannot be determined.[1] The outward form of the original mineral can still be observed, owing to the presence of some impurity in the infiltrating material which has preserved its outline by a thin encrustation. Sections in one plane are lath-shaped, measuring about ·003 inch × ·0006 inch, and in a plane at right angles to the former the shape is that of a hexagon. The complete hexagon has not been observed, two sides being absent where the mineral joins the wall of the amygdaloid; this is most usually the case in the tridymite of the Yellowstone. Often only two sides of the hexagon are seen. The general habit of the mineral strongly recalls the encrusting tridymite of the Yellowstone lithophysæ, and there can be no doubt, at least, that it is not due to deposition, in some unusual manner, by the infiltrating silica.

One rather interesting point follows. In some of the rocks a thin section reveals the presence of a number of incomplete spherulites, often fragmentary in appearance, and surrounded by secondary quartz. The structure is due partly to the presence of original gas-vesicles, partly perhaps to movement subsequent to the formation of the spherulites, and partly to brecciation after solidification.

Sometimes, however, the outlines suggest some amount of corrosion. It is possible to fix a date for the latter, owing to the typical development of the mineral resembling tridymite on such a corroded surface. We may suppose that the circulation of heated waters through the rock effected some corrosion, though not, I think, to any great extent, and that subsequently, when the temperature fell somewhat, tridymite, or a mineral closely resembling it, was deposited. (See fig. 2, III, p. 214.)

The obsidian of the Yellowstone region contains so large a number of porous spherulites, that in any investigation of older lavas at all comparable with the American rock one must be prepared to find indications, and probably abundant indications, of these peculiar structures.

The felspathic fibres, described and figured in the foregoing pages as projecting into the cavities of the spherulites from the old flows at Boulay Bay and Shropshire, as well as the open, non-compact nature of those parts of the spherulite which are adjacent to such cavities, show how closely these older lavas approximated to the younger in the conditions under which they solidified. The formation of a mineral suspiciously like tridymite clearly points in the same direction.

[1] The replacement of tridymite by quartz has been described by M. E. Mallard, Bull. Soc. Min. France, vol. xiii (1890) p. 161, from the Euganean Hills.

VIII. Pontesford Hill (Shropshire).

The rock of the north-western corner of this hill is almost identical with the rhyolite of Boulay Bay, and the nodules are quite indistinguishable from those of that rock.[1] The quartz-amygdaloids are rather irregular in shape, not infrequently stellate, and occasionally show some relation to the periphery of the enclosing nodule. As at Boulay Bay, lithophysæ are not common, and occasionally radial structure is not appreciable to a lens. The material in which the nodules are embedded is frequently greenish-brown, presumably once a glass, and contains small spherulites: it bears a very close resemblance to the devitrified glass of Boulay Bay. In thin sections we see that the nodules possess a well-marked spherulitic structure, resembling that observed in the Boulay-Bay rocks, but, in the cases examined, rather coarser than is usual in the Jersey examples. Admirable examples of the tufted form of growth are common, and these frequently project from part of the nodule into the quartz-amygdaloid. The resemblance to the structures already described from Boulay Bay and Wrockwardine is so close that no further mention is necessary.

IX. North Wales.

I have examined the nodular rock at Beddgelert (in passing), at Conway Mountain, and in the region of the Conway Falls and the Lledr Valley. In a former communication [2] I have referred to these rocks, and have nothing to add to what was then said. In the majority of cases, I believe that the conclusion brought forward by Prof. Bonney holds good:—namely, contraction around a cavity.[3]

X. The Hypothesis of Corrosion.

The continuity of lines of flow on either side of the star-like elongations of a central cavity have been considered [4] as a clear indication of corrosive action, and as a strong argument against the former presence of a vesicle which would have diverted the lines of flow. But we may also suppose that these star-like spaces arose from contraction on cooling, and consequent cracking which caused rupture without disturbing a structure previously acquired. In the hollow spherulites of Obsidian Cliff, irregular vesicles, with an inclination to be angular and even star-shaped, are far from uncommon, and apparently quite analogous to those from the older rocks.

Another feature brought forward in favour of the hypothesis of

[1] I am indebted to the kindness of Mr. W. Boulton, Assoc.R.C.S., who is engaged in a study of the rocks of this district, for permission to insert these remarks on Pontesford Hill.

[2] Quart. Journ. Geol. Soc. vol. liv (1898) p. 112.

[3] *Ibid.* vol. xxxviii (1882) p. 289.

[4] G. A. J. Cole, Quart. Journ. Geol. Soc. vol. xlii (1886) p. 183 & pl. ix, fig 1; see also Miss C. A. Raisin, *ibid.* vol. xlv (1889) p. 261.

corrosion is that brecciation-cracks widen in passing from matrix to spherulite.[1]

The nodules of Boulay Bay are frequently traversed by large numbers of brecciation-veins of different ages,[2] formed as a rule in radial directions, since these are the planes of easiest parting. In some the edges are distinct and sharp, in others they are blurred. On the whole, they are more numerous in the nodules than in the matrix. The older brecciation-veins are frequently clouded with brownish material, and disappear almost completely from view between crossed nicols, owing to the resemblance of the infilling material to that which constitutes the walls. As described in a former communication, a characteristic of these nodules is to break up, between crossed nicols, into a mosaic of interlocking irregular grains: often these are in optical continuity with the vein-substance. Indeed, in the older cracks we can nearly always find evidence to show that the sides are closely knit together, while in the newer the edges are sharp cut.[3]

The polygonal contraction-cracks around sundry spherulites from Boulay Bay do not appear abnormally wide, and they have of course been exposed to the action of any hot springs or fumaroles that may have existed. There seems, then, to be evidence, not of a widening by corrosion, but of a healing of the old fracture, and it is difficult to see how corrosion could act when once the vein was filled by so refractory a cement as silica. Were it half filled, and the means of transport less effectually blocked, the case might be different.

XI. General Conclusions.

In the second part of this paper I have endeavoured to elucidate some of the structures of the old lavas of Great Britain by a comparison with those of the Yellowstone region.

We have found in the rocks of Boulay Bay and Wrockwardine that the nodules contain amygdaloids of crescentic shape, passing into more or less completely circular rings, and we have compared these directly with the lithophysæ of the American obsidian. Moreover, we have found that felspathic fibres project outwards into a quartz-amygdaloid, that parts of some nodules show an open network of similar fibres now embedded in secondary material, and we have been able to draw a direct analogy with the porous spherulites of the Yellowstone. Finally, traces have been found of an encrusting mineral curiously resembling tridymite. All this militates strongly against an hypothesis of corrosion, so that we need feel no hesitation in applying to the older spherulites of Great Britain a conclusion which appears in accord with the facts observed in the rocks of the National Park of the United States.

In the case of the large amygdaloids, irregular, partly circular

[1] Quart. Journ. Geol. Soc. vol. xlii (1886) p. 185 & pl. ix, fig. 2.

[2] *Ibid.* vol. liv (1898) p. 115 & pl. vii, fig. 1.

[3] The brecciation-veins traversing the nodules of Pontesford Hill present identical features.

Fig. 1.

Fig. 2.

Lithophysae from Boulay Bay and Wrockwardine.

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or stellate in outline, I conclude that at these spots were gas-vesicles: such gases having been disengaged from the surrounding rock at the time when solidification began. In the case of the crescentic or annular amygdaloids I conclude that at these spots the magma was in an extremely hydrous state, and that the area now enclosed by the periphery of the nodule was practically composed of two parts, that is, magma and water. Hence the excess of either would crystallize out or separate out, as the case may be. As in the Yellowstone, the water charged with sundry substances in solution probably played some part in depositing encrusting minerals on the surfaces of the cavities.

In conclusion, I wish to express my grateful thanks to Prof. Bonney for much kind help in the microscopical work, and also for suggestions concerning the arrangement of the various parts of the paper.

EXPLANATION OF PLATE VIII.

Fig. 1. Lithophysal structure in a nodule from Boulay Bay. × 4.

2. Lithophysa from near Wrockwardine. The left-hand side is slightly dusty. On the right-hand side, the glass in which the lithophysa lies is visible. × 4.

Discussion.

Prof. Bonney congratulated the Author on the good use that he had made of his visit to the Yellowstone region, and expressed concurrence with the results at which he had arrived. The paper would put an end to the idea (in which the speaker had never believed) that hollow spherulites were formed by decomposition at the centre, and it had shown them to have been formed about an original cavity. Discontinuity of any kind, as the speaker had pointed out in 1885, was peculiarly favourable to the formation of spherulites. In the case of glass-bottles, softened by heat, they developed abundantly from the inner and outer surfaces; and similarly in sheets of glass, which had become adherent through heat. In the case of the formation of a spherulite round a cavity, crystallization might be facilitated by the pressure of the imprisoned vapour being outwards on the enclosing hardening mass; but in other cases, before that had time to produce an effect, the vapour, contracting more rapidly than the rock, might cause strains in it: sometimes, as the Author had suggested, magma and vapour might be mixed in the interior, producing either alternating zones of rock and excluded vapour, or loose spongy crystallization. As the audience had not properly seen the slices, owing to the partial failure of the lantern, he might say that he had examined the supposed tridymite in the British specimens, as well as the other structures described by the Author, and thought the former presence of that mineral highly probable, for that it should be replaced by a quartz-paramorph was not unlikely. He thought that the Author had proved that what the Yellowstone obsidians now were, this the felstones of Boulay Bay, Pontesford, and Wrockwardine had once been.

The Author briefly replied.